8. Societal and Policy Implications of Solar Thermal Power

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8.1 Emissions of Power Plants

Specific emission levels of a power plant (e.g., units of CO_2 per unit of electric energy) depend on fuel type and the conversion efficiency from fuel input to electric output. The entire “conversion chain” is schematically shown in Figure 8-1.

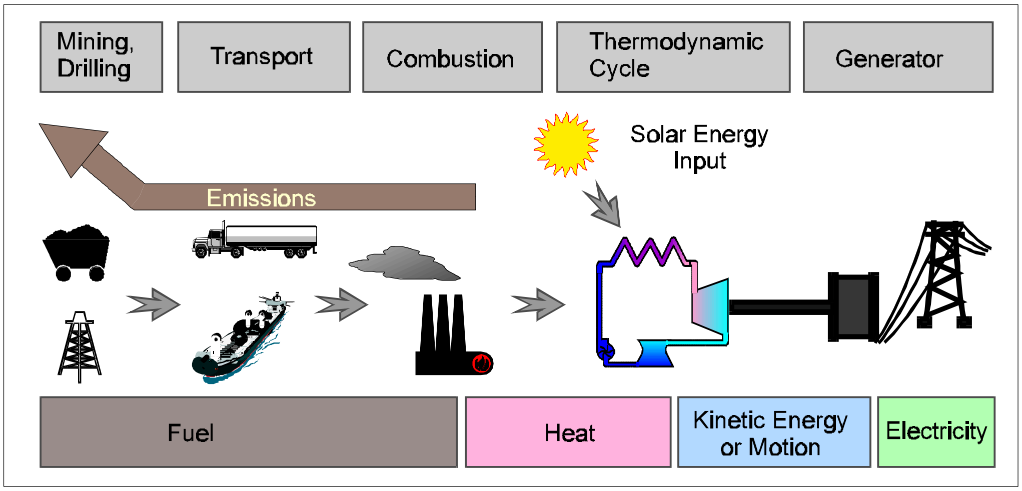

Figure 8-1 Energy-to-Electricity Conversion Chain

Fuel Types: The carbon based fuels - coal, oil, and natural gas - vary in their composition, suitability for particular processes, and the amount of usable heat per unit of fuel (the lower heating value, LHV). Natural gas, mainly consisting of methane (CH_4), has a negligible sulfur content along with the lowest carbon content of all fossil fuels and is therefore regarded as the cleanest of all fossil fuels. Its hydrogen content is the highest among carbon based fuels, and its combustion results in the formation of less CO_2 but more H_2O than with other fuels. Heavy fuel oil is a by-product of the refining process; put simply, it is the remainder of the crude oil after gasoline, kerosene and diesel are extracted. Coal is, of course, a solid fuel and this impedes its handling. Coal mainly consists of carbon but frequently contains substantial amounts of unwanted ashes and sulfur. Figure 8-2 shows the amount of CO_2 generated in combustion by different fuels when burning the same calorific amount of fuel (i.e., the quantity which gives off the same quantity of heat).

Natural gas is regarded as the cleanest of all conventional fossil fuels

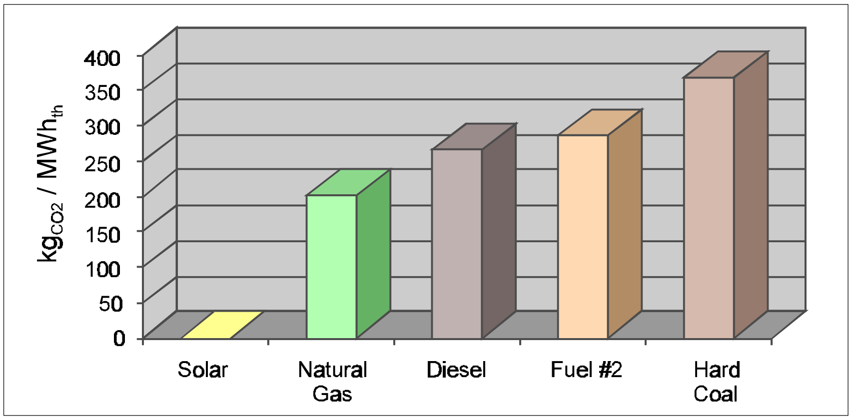

Figure 8-2 CO_2-Content per MWh Lower Heat Value of Different Fuel Types

Transport "Efficiency": The transport of energy is itself energy consuming. For example, to transport gas from Siberia to western Europe over a distance of 6,000 kilometers requires the equivalent of 10.6% of the gas energy for pumping to overcome pressure losses in the gas pipeline. Liquid natural gas, LNG, requires even more energy for its liquefaction, which alone accounts for up to 20% losses. Transporting oil over the same distance in a pipeline takes 2.6% off its energy value. While oil tankers need less energy per ton-kilometer than pipelines, consumption is high because the distances are usually greater. Tanker transport consumes 1.6% of the energy content over a distance of 10,000 km; thus an oil tanker traveling from the Persian Gulf to Europe around the Cape (18,000 km) consumes 2.9% of the oil it transports. Transporting coal from South Africa would also be similarly energy intensive.

Before a fuel reaches the power plants the equivalent of 5 to 20% of its initial energy value has been consumed for transport

Conversion Efficiencies: Figure 8-1 shows that converting a fuel into electricity takes several steps, with each one passing only a fraction of the energy that was previously in the fuel onto the next conversion step. While the efficiency figure most commonly discussed is the steam cycle efficiency, examining all the steps in the process is instructive. Figure 8-3 traces the steps in a steam Rankine cycle fueled by coal. In this figure, the width of each arrow is proportional to the magnitude of the energy flow, and the number gives the percentage of the initial energy. Note that in a steam turbine plant there are different subsystems that contribute to the overall efficiency: the boiler (combustion and steam generation) with efficiencies from 80 to 94%, the steam or Rankine cycle itself, where a portion of the heat is converted into motion and the rest has to be rejected in a cooling system (30-44% efficiency), and the generator where the gross electricity is generated (up to 98% efficiency). Finally, the electricity that the subsystems of the plant consume - called parasitics - is subtracted to derive the net electricity that can be fed into the grid. This diagram illustrates the peak or maximum efficiency. In a solar plant, a more meaningful value is the average efficiency at realistic conditions over a whole year, with start-up losses, losses during transients, and losses due to operation at off-design conditions.

The true efficiency of the electric conversion cycle includes all the steps from fuel extraction to net electricity

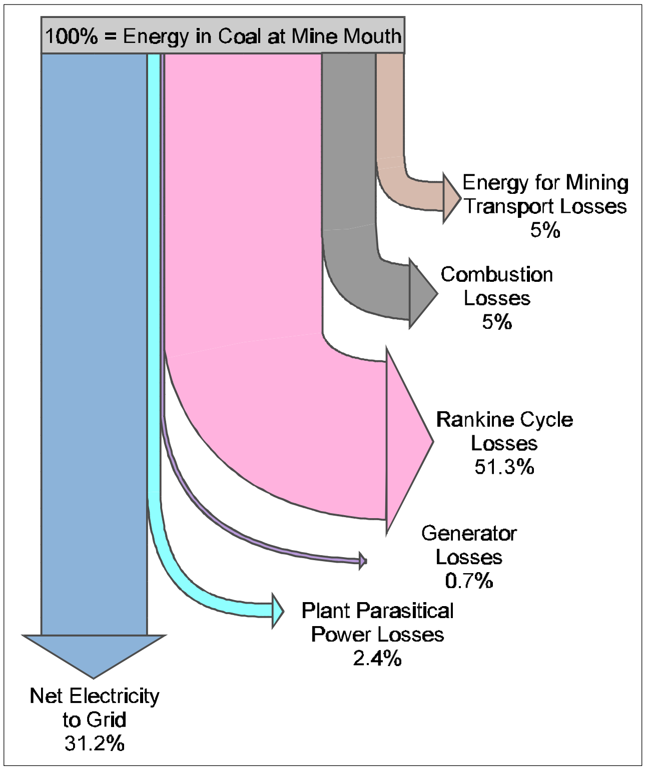

Figure 8-3 Energy Flow of a Coal Fired Rankine Cycle

A combined cycle (CC) utilizes the fuel energy in two steps by combining two processes. First, the fuel is combusted in a gas turbine (GT). Then the flue gases from the gas turbine enter the waste heat recovery system (WHR), where its energy is transferred to the steam cycle. The WHR has the same function as a boiler, that is, to generate and superheat steam. From here the conversion is analogous to the Rankine cycle describe above. Combined cycles with net electric efficiencies of 53% (at standard conditions) are currently operating, and the latest generation of high performance gas turbines is expected to exhibit 58% net CC-efficiency. Figure 8-4 shows the energy flow in a natural-gas-fired combined cycle plant. The combined net electric efficiency illustrated here is 45.8% when accounting for all losses, including transport.

Combined cycle net electric efficiencies can exceed 55% at design point

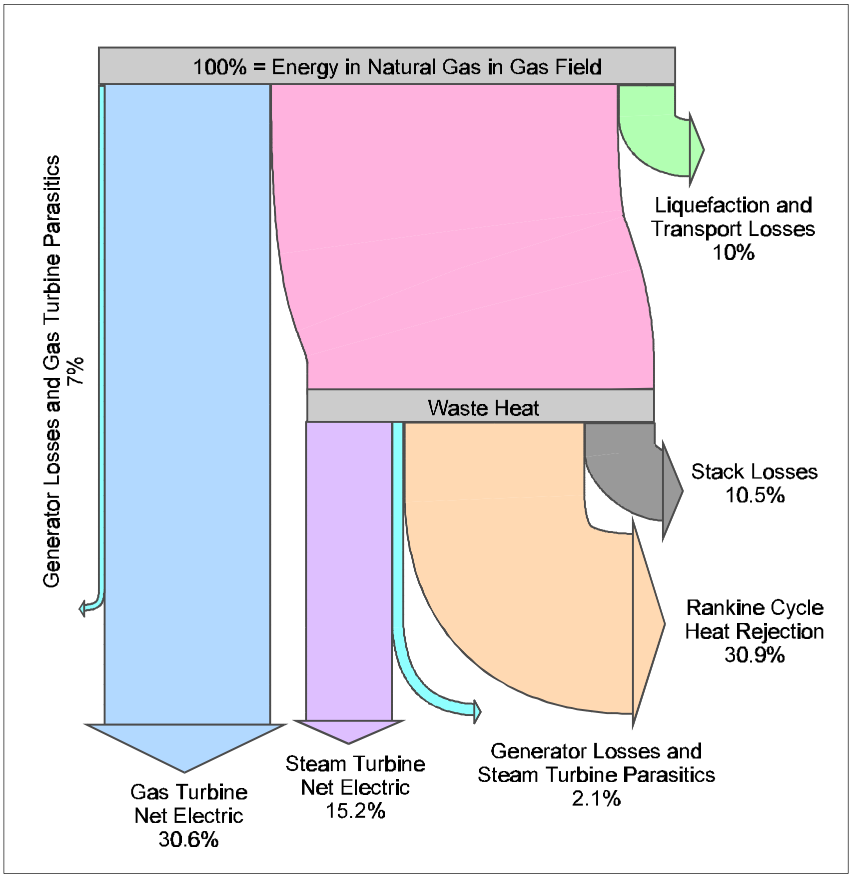

Figure 8-4 Energy Flow of a Natural Gas Fired Combined Cycle

8.2 Emissions Reductions with Solar Thermal Power Plants

Generally, the major emissions from burning fuel are carbon dioxide (CO_2) and water (H_2O). Other emissions included carbon monoxide (CO), hydrocarbons (C_nH_m), nitrogen-oxides (NO_x), and sulfur-dioxide (SO_2), which can be lowered by better controlling the combustion process, by flue gas desulfurization (FGD), or via selective catalytic reduction (SCR). However, there is no economical solution to extract CO_2. Although not toxic, CO_2 discharged to the atmosphere from combustion contributes approximately 40% of the global warming effect (discussed in section 1). The following refers to electricity production which still is responsible for 11% of all greenhouse-effect-relevant emissions.

Although not toxic, CO_2 discharged to the atmosphere from energy-related combustion constitutes approximately 40% of the global warming effect

Typical CO_2-Emissions: Emission levels in terms of kilograms CO_2 per kWh of electricity depend on the fuel and the electrical conversion technology. Figure 8-5 shows the emissions of several typical combinations of plant and fuel types. The emissions of SEGS plants are shown both for solar only operation and for the hybrid mode of operation where partial fuel use adds emissions to the case where the solar field supplies the equivalent of about 2000 full electrical load hours per year.

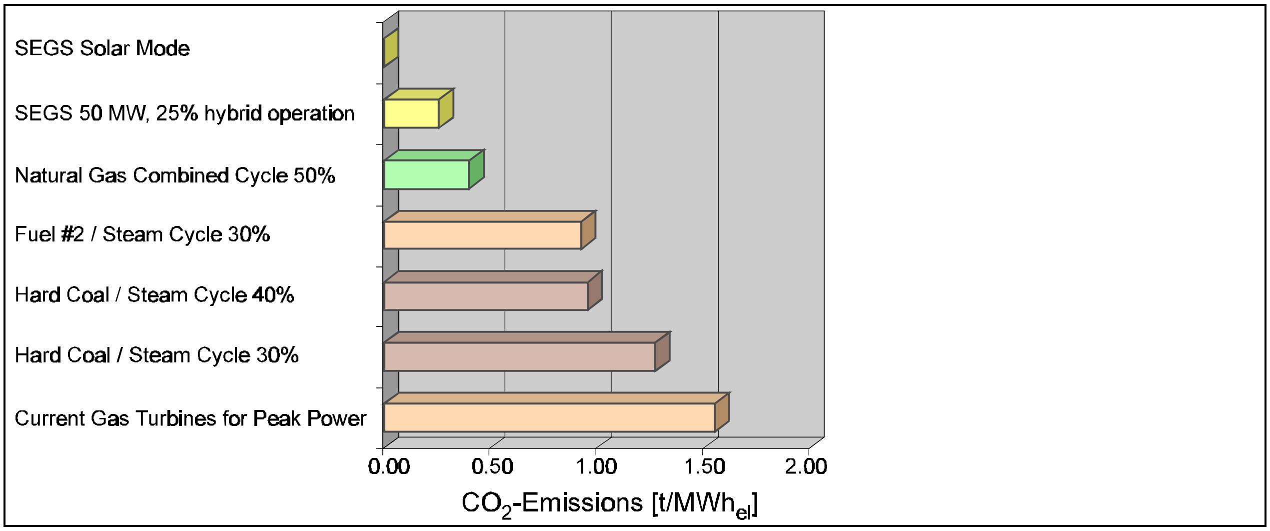

Figure 8-5 CO_2-Emissions of Different Power Plants

Figure 8-6 compares the daily emissions reduction potential of an 80 MW solar trough power plant with thermal energy storage with other technologies, assuming a typical mid-load operating scenario. The SEGS plant operates like a conventional steam power plant if solar energy is not available. Figure 8-7 presents a similar comparison for an 135 MW Integrated Solar Combined Cycle System.

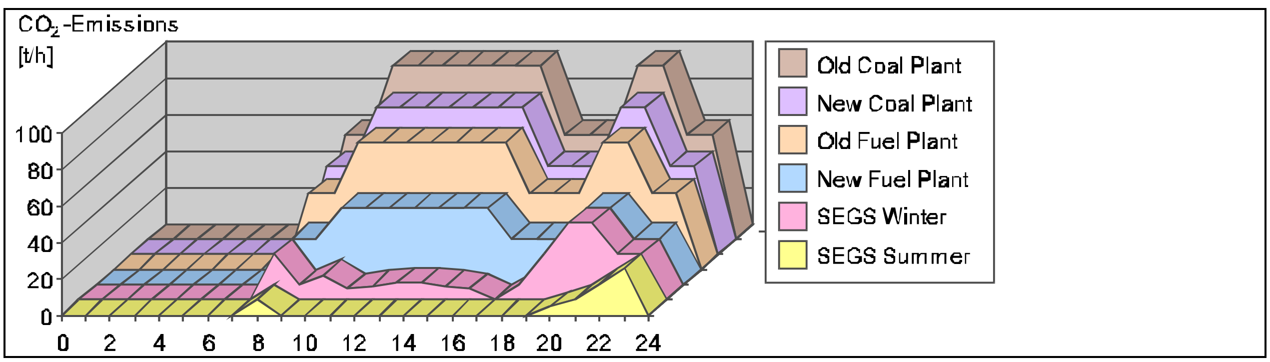

Figure 8-6 CO_2-Emissions of Various 80 MW Power Plants in a Daily Cycle

CO_2-Emissions Savings: With current technology, each square meter of solar field can produce up to 1200 kWh thermal energy per year or nearly 400 kWh electric per year. Taking into account the average European CO_2-emissions of 1 kg per kWh_e, there results a cumulative saving of 10 tons of carbon dioxide per each installed square meter of solar field over its 25 year lifetime.

With current technology, each square meter of solar field saves 10 tons of carbon dioxide over its 25 year lifetime

A well-sized solar field can supply up to 2,000 full load hours per year, or about 6 hours per day, to a steam cycle. If an average plant is operated 4,000 hours per year, adding a solar field can cut emissions by 50%. For example, an 80 MW solar power plant (as shown in Figure 8-6) can save 186,000 tons of CO_2 or 80,300 tons of coal equivalent each year.

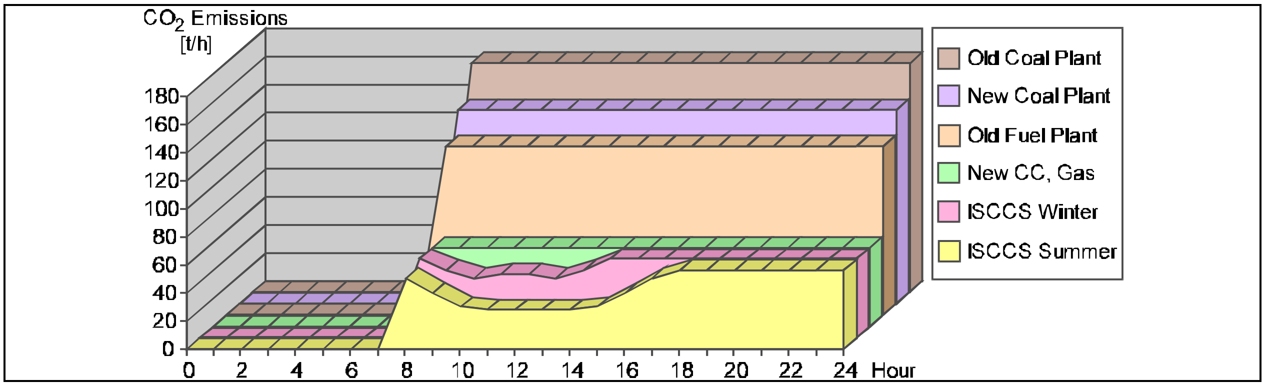

Figure 8-7 CO_2-Emissions of Various 135 MW Power Plants in a Daily Cycle

CO_2 Avoidance Cost: Once the technical potential of reducing CO_2-emissions using solar thermal power plants has been postulated, it remains to calculate the cost of this environmental measure. A straightforward approach is to calculate comparable levelized electricity costs (see section 7) of a solar plant and a reference conventional power plant, and to then normalize the incremental cost by the amount of saved emissions. Comparing an oil-fired plant to a SEGS type plant, saving a ton of CO_2 costs about 120 USD. Integrating a solar field with a natural gas fired combined cycle (ISCCS) results in costs of approximately 195 USD per ton of CO_2. However, comparing the SEGS plant to a coal fired plant, the costs reduce to about 50 to 55 USD per ton of CO_2. This particular calculation is somewhat biased because CO_2 is not the only pollutant generated by combustion and, consequently, a more equitable method would be to distribute the additional costs among the other emissions (NO_x, SO_2, particulates). In general, however, if an estimate is made of total societal costs due to all emissions, the impact of CO_2 can be expected to represent over 85% of the result.

Other Solutions to CO_2-Emissions Problems: Ideas have been developed to apply "end-of-the-pipe" reduction methods for CO_2, as has been done successfully with SO_x, NO_x, and particulates. This would consist of extracting the CO_2 from the flue gases, compression and deposit into an empty natural gas field or disposal in fluid or solid form into the oceans. However, experts calculate that separation of CO_2 from the flue gases would consume 10 to 20 % of the electricity generated from burning of the fuel, and the energy to further process it would be 100 to 400 kWh per ton CO_2 (another 10-20% of the generated electricity). The costs involved would be on the order of the current cost of coal, e.g., multiplied by the factor of 1.5 to over 3.

8.3 Land Use of Renewable Technologies

Land use is sometimes cited as a concern with renewables, which are viewed as land intensive technologies. This is a natural and legitimate consideration as the use of renewables increases, for sufficient areas have to be available in suitable locations. Figure 8-8 compares the land use of several existing solar thermal and hydro-electric projects. As can be seen, solar thermal plants require far less land than hydropower systems. Furthermore, the area used for solar thermal power is often desert land whereas land inundated by a dam is often more productive.

When comparing the land use of renewables with other energy sources requires, however, a general perspective is appropriate. For example, areas for mining and transport of fossil fuels need to be included for an equitable comparison to renewables.

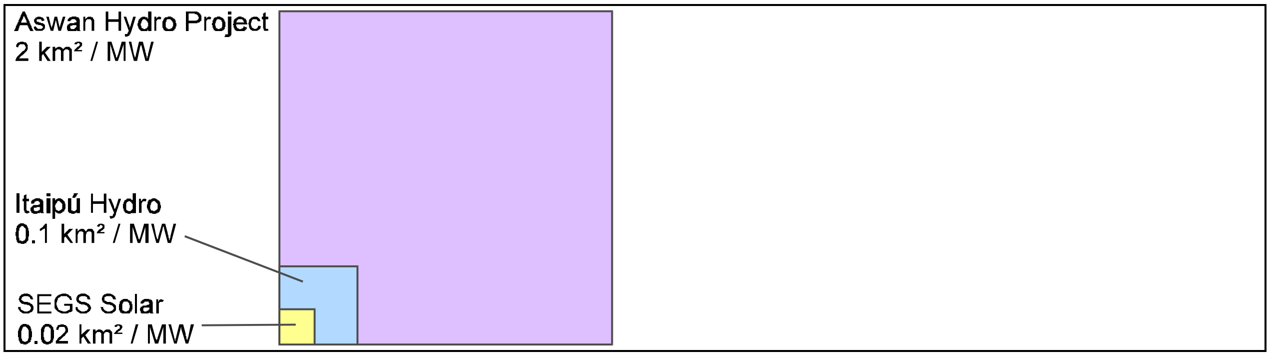

Figure 8-8 Land Use of Different Renewable Technologies

Solar thermal technology requires far less land than most hydropower projects

Consider, for example, a future world electric demand of 5 million MW (anticipated for the next 30-49 years). If this capacity were met employing solar thermal technology, the land use would be about 100,000 square kilometers or, to put it in perspective, the equivalent of 0.3% of the current land for food production.

8.4 Energy Policy Considerations for Potential SEGS Host Countries

The need for formulation of a consistent energy policy recognized in the early 80's when the oil price crises caused significant energy market turbulence, unpredictable price fluctuations and severe effects on the overall growth expectations of industrialized countries as well as the developing world. Prior to the oil price crisis, energy policies of the industrialized countries sought self-sufficiency in the first half of this century and then evolved into increased international primary energy trade in the post-second-world-war phase. Developing countries were basically establishing an electrical infrastructure to keep pace with the expected economic growth after independence. The rapidly growing infrastructure for crude oil transport and conversion facilities resulted in lower fuel prices and led to the situation that most of the developing countries relied heavily on fuel oil imports. The oil price crisis put a burden on these countries which was much more severe than in the industrialized world, as financial resources were scarce and rapid investments in alternatives could not generally be financed.

With the experience of the two oil price crises, OECD countries defined joint action plans to reduce their dependency on oil and gas with coordinated policies, generally characterized as follows:

- minimizing the overall electricity production costs in the national supply system,
- diversifying the energy carriers on which power production is based,
- attracting investments in fuel efficiency and energy conservation, and
- increasing the flexibility of the power system vis-à-vis electricity demand changes

With the increasing recognition of environmental impacts caused by energy and electricity production, most of the OECD countries additionally added the following policy objectives:

- supporting investments for minimizing emissions related to energy conversion,
- intensifying efforts for energy conservation and efficiency, and
- supporting the introduction of renewable energy technologies.

Although solar thermal power plants can be efficiently operated in only a limited number of OECD countries, e.g., the Southwest United States, southern Spain, Italy, Greece and Australia, this technology is able to approach many of the energy policy goals formulated above.

Using a renewable energy source, they are able to reduce the dependency on imported fuels and to help diversify the mix of energy sources. They have low or zero emissions and enhance the flexibility of the electricity sector vis-à-vis electricity demand changes as due to short construction times, small to medium capacity sizes and operation as peak- to mid-load plants with minimal fossil fuel combustion. Solar thermal technologies also have the capability to expand their operation to base-load with additional fossil fuel.

However, being capital intensive, renewables conflict at today's low fossil fuel prices with the goal of minimizing electricity generation cost and related investments. Nevertheless, energy policy is always characterized by compromises and a combination of measures to address the various, sometimes conflicting, goals. In most cases, e.g., the goal to increase the utilization of domestic energy resources, achieving objectives will result in higher investment cost because the formulation of the goal itself means that less costly means have been used in the past.

Energy policy goals in developing countries are very much influenced by the concerns which arose with the oil price crises. They typically seek:

- ❑ reduction of the dependency and minimizing the expenditures on imported fuels,
- ❑ development of domestic energy resources,
- ❑ development of the electricity sector to cope with the economic development, and
- ❑ providing low cost electricity to strategic export industries and the rural sector.

Even more pronounced than for OECD countries, solar thermal power plants can address the majority of policy goals. They are a fuel saver by definition and a domestic energy resource. They help reduce fuel dependency, although with low world market prices for fossil fuels this ability is presently of less economic relevance. Furthermore, solar power plants have a utilization advantage in the developing world as most of this group of countries are situated in the sun belt, resulting in more efficient and economic operation of these plants. The need to electrify the rural sector opens a specific advantage for smaller solar power concepts as they are already cost efficient when fuel transport is expensive.

Renewable technologies minimize the dependence on fuel imports

However, the cost related goals of these energy policies cannot be met today with renewables due to current low implementation rates and competing low fuel prices. Even more importantly, the financial weakness of the developing world limits current investments in capital intensive power technology in the absence of the pressure caused by high fuel import prices. Several countries from the developing world, namely India, Pakistan, Jordan and some Latin American and Caribbean countries, have developed ambitious schemes to further the rapid market introduction of renewable power technologies. But these countries, focusing on the recovery of the electricity sector to keep pace with the economic development, are also restricted in their ability to finance the additional cost of investments in renewable power technology. Compared to the specific CO_2 emissions per capita of OECD countries, the per-capital emissions of the developing countries are several factors lower, leading to the conclusion that the burden on environmentally responsible power generation should basically be carried by the OECD countries.

8.5 Labor Benefits of Solar Thermal Power Plant Implementation

The higher up-front cost of renewable technologies results in immediate gains in employment and fuel cost reductions. Additionally, the labor gains can often be sourced locally.

This is specifically true for solar thermal power plants of the parabolic trough type. Most of the equipment and construction materials needed for the solar field are conventional, and can be procured domestically - see section 6.3 - in the group of countries which show highest comparative advantage for solar thermal power generation in the developing world.

Renewable technologies such as solar thermal power plants typically mean increased labor opportunities to the implementing country

Evaluation of the domestic supply capability of selected countries indicates, even for the first project, shares in a range between 41 to 52% of the total project volume, as illustrated in Figure 8-9. This supply share can be increased for subsequent projects if domestic supply industries adopt an increased production of solar field and power block components, which is of course beneficial to the local economy but subject to competition on an international scale.

Erection and operation of the nine SEGS power plants in California provide an indication of labor requirements (see also section 4.2):

- ❑ During the construction period there is a peak of about 1,000 construction jobs for a period of approximately 1 year at the site
- ❑ The operation of the plants requires for each project of the 80-100 MW SEGS and 100-250 MW ISCCS class about 50 permanent qualified jobs on the plants, primarily operators, a maintenance group and plant administration

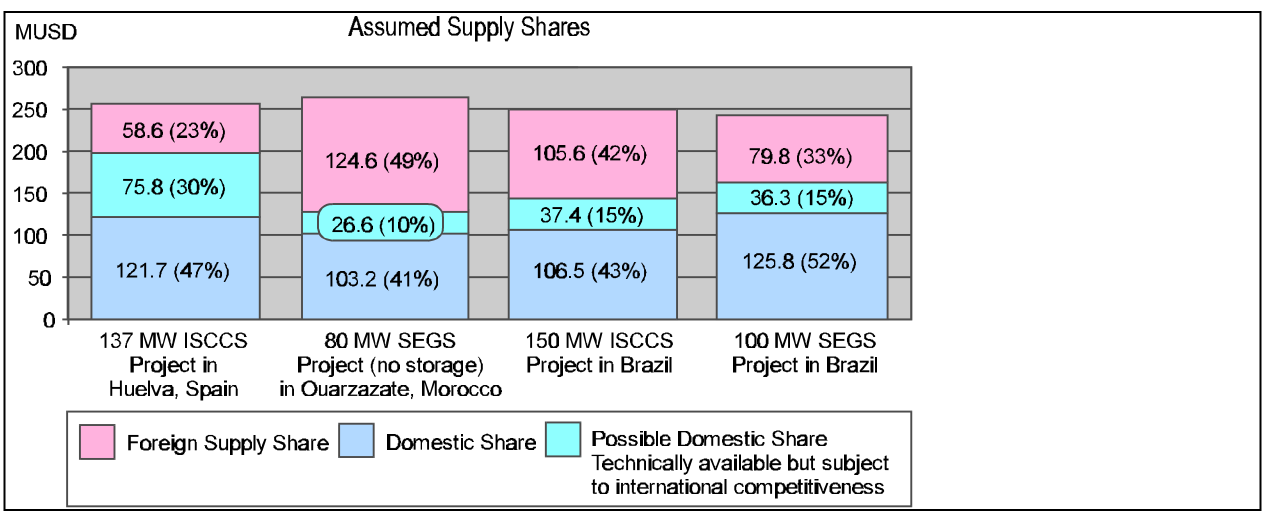

Figure 8-9 Domestic Supply Shares for Solar Trough Projects in Selected Countries

Due to the economies of scale, larger unit sizes of solar thermal power plants on the order of 200 MW capacity will significantly reduce the specific investment cost but may, at the same time, raise the domestic supply share thereby adding to labor requirements during construction and subsequent operation.

Figures

9. Market Perspectives for Solar Thermal Power Plants

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9. Market Perspectives for Solar Thermal Power Plants

Having established the status of solar thermal technology, we now explore a crucial issue - can this technology compete in the near-term to mid-term market and beyond? In a market which values only the “bottom line” - the lowest cost - there are very few electric market segments where solar thermal plants can immediately compete. This discussion will not deal with the relatively small niche markets where kW-scale photovoltaic systems are making an entry and where dish/Stirling systems see opportunities, rather it will focus on the emerging market on a global scale where major investments will be attracted to respond to the power demands of rapidly growing economies. Competition will be intense to supply bulk electricity production and capture its attendant financing to satisfy required electricity needs for the mega-cities and industrial growth, but accomplished in such a way that the environment is protected.

Following the arguments of section 2, the market success of solar thermal power plants and other renewables will be heavily dependent on the choices made between environmental protection and the lowest possible electricity cost. Being in many ways mutually exclusive, the final outcome will depend on both energy policy decisions and international support for responsible environmental actions in a climate of scarce financial resources.

The looming market is enormous. The IEA foresees the world’s electricity demand on the order of 20,500 TWh/y in 2010, extrapolated to 26,000 TWh/yr in 2020, while the World Energy Council (WEC) estimates a comparable 23,000 TWh/yr in 2020. Estimates focusing on the possible role of renewables, such as the Response Strategies Working Group (RSWG) of the Intergovernmental Panel on Climate Change, assume lower electricity demand levels due to the intensified introduction of energy efficient technologies, leading to an expected demand of 21,000 TWh/yr in 2025. A main difference in these statistics is the predicted penetration rate of renewable (excluding hydro) power technologies. The IEA expects renewable electricity production to rise from 40 TWh in 1991 to 191 TWh in 2010 (a 1% market penetration) while the RIGES[1] study expects renewables to contribute 4,651 TWh/yr in 2025, a contribution of 22% to the global electricity supply.

What will be the role of solar thermal technology and other renewables in the enormous energy demand growth over the next few decades, and to what extent can they compete?

What will be the role of solar thermal technology and other renewables in this growth, and to what extent can they compete? Such questions clearly call for a better understanding of the expected evolution of the world power market and the renewable energy segment. In particular, are there potential market segments where solar power can develop on a large scale should policy incentives allow, that is, in a market framework which accommodates early introduction of solar thermal power even at low

[1] **R**enewable **I**ntensive **G**lobal **E**nergy **S**cenario (RIGES) from Johansson et. al. which is based on the RSWG study and deals with intermittent renewables (wind, solar thermal and PV)

fossil fuel price levels and despite an initial cost disadvantage? The following discussion explores some answers to these questions.

9.1 Anticipated Evolution of the World Power Plant Capacity in the Sun Belt - a Market Perspective for Solar Power

First, we will examine the expected capacity increase for 11 world regions for the time steps 1991, 2000, 2010 and 2020, based on IEA projections of electricity demand[2] and our own extrapolation for 2020 using the low-side demand growth rates of the 1991-2000 period with an assumed saturation in electricity demand for some regions. This 30-year time frame is of interest as it corresponds to the life cycle of a thermal power plant park.

The analysis was done by region not only because development differs significantly between OECD countries and less-developed countries, but also to identify those geographical areas where solar thermal power plants can operate most efficiently, i.e. in the sun belt of the world. For these purposes, entire regions with few prospects for solar thermal application were not included in the analysis -- areas such as Central and Eastern Europe, OECD Europe, countries of the former Soviet Union and East Asia. Although efficient solar thermal power generation can be justified in some Southern OECD Europe countries where specific interesting solar project developments are currently underway, the long-term potential for this group of countries was not considered to be significant on a global scale due to land competition and other factors.

Status 1991							
Region	Elec.demand Total [TWh/yr]	Hydro [TWh/yr]	Capacity Thermal [GW]	at full load hrs [hrs/yr]	Hydro [GW]	at full load hrs [hrs/yr]	Solar Potential *
North America	3,705	577	845	3700	144	4000	33%
OECD - Pacific (Japan, Austr., N.Z.)	1,069	136	233	4000	37	3700	20%
South Asia (Indian Subcont.)	369	91	71	3900	27	3400	100%
China	677	125	89	6200	35	3600	20%
Middle East	228	10	53	4100	3	4000	100%
Africa	330	60	64	4200	20	3000	100%
Latin America	632	408	75	3000	91	4500	33%
All regions	**7,010**		**1,431**		**355.7**		
Total world electr. demand	**12,030**		* percentage of net thermal capacity increase				

Table 9-1 Power Demand and Related Capacity / Status 1991

The results of the first step in the analysis are given in Tables 9-1 and 9-2, and summarized in the first bar of Figure 9-1. To supply the electricity demand in the selected regions, which constitute 61% of the total world's electricity demand, a thermal plant capacity of about 1,738 GW is necessary by the year 2000 (and another 512 GW of hydro), implying additional capacity requirements of 307 GW thermal and 156 GW hydro electric plants. Assumptions were also made on the replacement rate of old

[2] The translation from expected electricity demand to a corresponding capacity required an assumption of average full load hours for thermal and hydro electric facilities based on UN energy statistics from 1990.

equipment. This replacement rate was estimated to be 30% of the existing power plant park for thermal units and 15% for hydro electric units over one decade, resulting in average life cycles of 33 years for thermal plants and 66 years for hydro plants.

Decade 1991 - 2000										
Region	Replacem. Capacity		Elec.Demand		Required Capacity				Potential Solar Segment [GW]
	Thermal [GW]	Hydro [GW]	Total [TWh/yr]	Hydro [TWh/yr]	Thermal [GW]	at full load hrs	Hydro [GW]	at full load hrs	
North America	254	22	4,316	707	925	3,900	186	3,800	27
OECD - Pacific (Japan, Austr., N.Z.)	70	6	1,334	148	289	4,100	41	3,600	11
South Asia (Indian Subcont.)	21	4	543	166	94	4,000	49	3,400	23
China	27	5	1,204	271	153	6,100	73	3,700	13
Middle East	16	0	383	18	87	4,200	5	4,000	34
Africa	19	3	451	66	91	4,250	23	2,900	26
Latin America	22	14	901	596	98	3,100	135	4,400	8
All regions	**429**	**54**	**9,132**	**1,972**	**1,738**		**512**		**142**
Total world electr. demand			**14,976**						
Net capacity increase					**307**		**156**		

Table 9-2 Power Demand and Related Capacity / Decade 1991 - 2000

Decade 2001 - 2010										
Region	Replacem. Capacity		Elec.Demand		Required Capacity				Potential Solar Segment [GW]
	Thermal [GW]	Hydro [GW]	Total [TWh/yr]	Hydro [TWh/yr]	Thermal [GW]	at full load hrs	Hydro [GW]	at full load hrs	
North America	280	28	5,202	757	1,084	4,100	199	3,800	53
OECD - Pacific (Japan, Austr., N.Z.)	87	6	1,811	172	390	4,200	49	3,500	20
South Asia (Indian Subcont.)	28	7	1,010	355	160	4,100	108	3,300	66
China	46	11	2,094	488	268	6,000	128	3,800	23
Middle East	26	1	652	31	146	4,250	8	3,900	59
Africa	27	3	657	73	136	4,300	26	2,800	45
Latin America	30	20	1,372	909	140	3,300	211	4,300	14
All regions	**524**	**76**	**12,798**	**2,785**	**2,324**		**730**		**280**
Total world electr. demand			**20,450**						
Net capacity increase					**586**		**218**		

Table 9-3 Power Demand and Related Capacity / Decade 2001 - 2010

Decade 2011 - 2020									
Region	Replacem. Capacity		Elec.Demand		Required Capacity				Potential
	Thermal	Hydro	Total	Hydro	Thermal	at full load hrs	Hydro	at full load hrs	Solar Segment
	[GW]		[TWh/yr]		[GW]				[GW]
North America	324	30	6,060	909	1,226	4,200	239	3,800	47
OECD - Pacific (Japan, Austr., N.Z.)	117	7	2,264	226	474	4,300	65	3,500	17
South Asia (Indian Subcont.)	48	16	1,486	520	230	4,200	158	3,300	70
China	80	19	3,141	732	402	6,000	188	3,900	27
Middle East	44	1	978	47	217	4,300	12	3,800	70
Africa	41	4	898	100	186	4,300	36	2,800	50
Latin America	42	32	1,956	1,271	196	3,500	303	4,200	18
All regions	**696**	**109**	**16,783**	**3,805**	**2,930**		**1,000**		**300**
Total world electr. demand			**26,178**						
Net capacity increase					**606**		**270**		

Table 9-4 Power Demand and Related Capacity / Decade 2011 - 2020

Solar energy can realistically satisfy but a portion of this potential. Although the selected regions offer good possibilities for the operation of solar thermal plants, it was recognized that solar technology faces limits in the supply of the long-term growth given variations in solar resource and geography. The North American continent, e.g., offers superb conditions for solar thermal plants but only in the southwest region. Furthermore, the replacement capacity was assumed to favor non-solar options because of the existing infrastructure. Therefore, only 33% of the net thermal capacity increase was assumed to be a potential target for solar power generation. On the other hand, the majority of the developing countries lie within the sun belt, thus offering similar or better solar resource conditions coupled with greater capacity addition needs. Hence, we have assumed that 100% of the anticipated net thermal capacity additions are potential targets for solar power plants in areas such as Africa, the Indian subcontinent and the Middle East.

The next two decades were analyzed in the same manner, with the results presented in Tables 9-3 and 9-4. Figures 9-1 and 9-2 display graphical summaries of the findings.

For the year 2000, a potential solar thermal market segment of 142 GW has been forecast in the selected regions, which is 46% of the net new thermal capacity increase and only 19% of the total thermal capacity additions needed in that decade. With a rapidly growing capacity requirement in 2010 this potential market segment nearly doubles, though still constituting only 25% of the total thermal capacity additions. In 2020 this projection rises to 303 GW, only a slight increase due to assumptions on the saturation of the power markets.

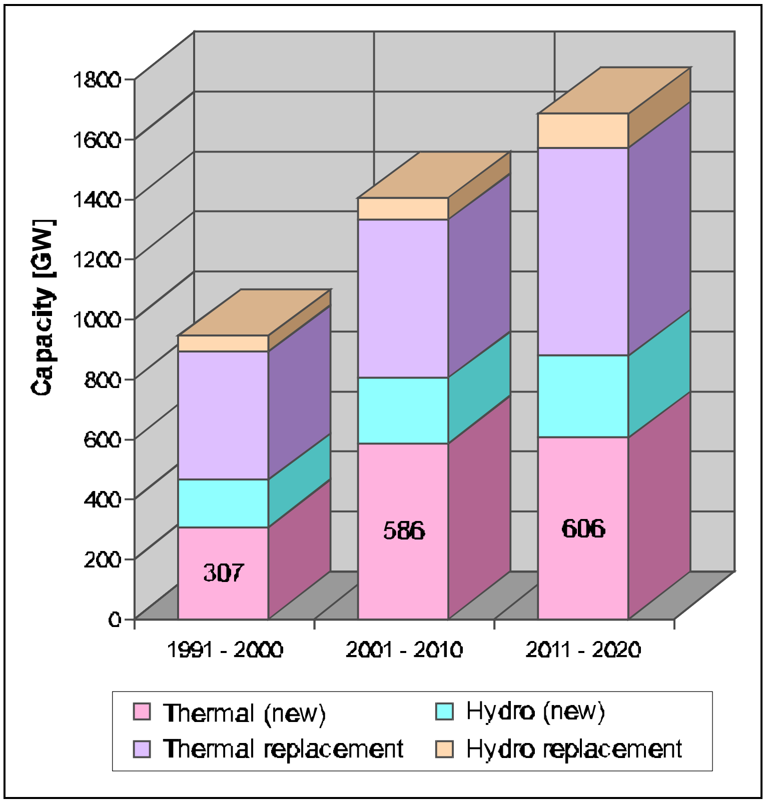

Figure 9-1 Incremental Power Plant Capacity Needs 1991-2020

A key question, however, centers on the extent that new solar thermal plants can move into this favorable market segment. Our assumption is that the market penetration will be 1% in 2000, 5% in 2010 and 10% in 2020. Applying these values gives the projected market penetration of solar thermal plants shown in Figure 9-2.

We roughly estimate a solar market penetration of 1.4 GW by the year 2000-2005, 4 GW by 2010 and 10 GW by 2020

But can these proposed market penetration rates be realized? With current market conditions in bulk electricity production solar thermal power needs incentives to compete. Without doubt the time horizon is too short to expect 1420 MW of solar thermal capacity to be constructed by the year 2000. Even given an existing planning pipeline of 600 MW SEGS and ISCCS projects (the purely solar portion[3] of these plants is about 300 MW), realization of all potential project developments is unlikely, suggesting that only part of the assumed market penetration can be realized. Considering the planning and financing lead time required, we might expect the 1460 MW market penetration about 2005. The next time step to 2010 is very ambitious and requires an annual implementation rate of 1400 MW of solar thermal capacity or more (about 5% of the potential) if the 2000 estimate could not be achieved.

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[3] In a hybrid solar/fossil-fuel plant, only part of the capacity is attributable to solar energy. The solar energy contribution to annual output depends on configuration and operating scenario. In an ISCCS plant, for example, the annual solar share is about 10-20% of the output at a capacity factor of 80-90%. For lower capacity factors the solar share rises proportionately.

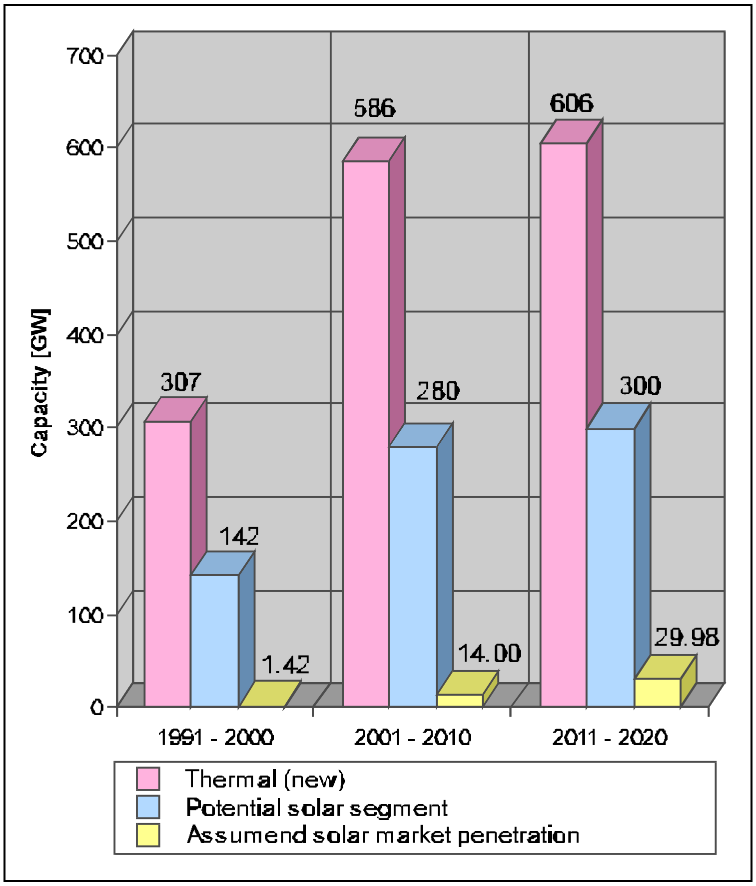

Figure 9-2 Assumed Market Penetration of Solar Thermal Power Plants

Nevertheless, a number of other factors suggest optimism. A global policy of clean power generation will require capacity increases of the projected magnitudes to achieve a significant contribution of solar power. The first solar thermal project developments will be the most demanding, with subsequent additions less complex. The other major solar thermal technologies - central receivers and parabolic dish/Stirling systems - will likely be commercialized during this period to complement the growth of parabolic trough plants. Early crucial steps for solar thermal projects include establishment of adequate compensation rates for clean electricity, revived or emerging supplier and industrial infrastructures, and appropriate initial incentives from financing organizations and governments to make solar thermal power competitive. As the market develops, mass production will reduce investment costs. Larger plant capacities, in the 150 - 200 MW range for SEGS and 300 - 600 MW sizes for ISCCS plants, will further improve economics. If anticipated increases in fossil fuel prices also occur, no further financial incentives will be needed and the solar thermal power plant capacity can achieve a sustainable growth to about 10% of the electric market in 2020.

9.2 The Need for a Reliable Framework

The experience of the SEGS plants in California showed that reliable and consistent energy and taxation policies are needed to attract investments in renewable power technology. In countries where the regulatory framework does not yet incorporate instruments for attracting renewable power investments except, at a minimum, a fair rate of compensation based on the real avoided cost of energy and capacity, initial incentives or subsidies for solar thermal power projects will be a necessity. In this initial phase multilateral and bilateral financing institutions must help to bridge the economic gap between conventional fossil based power generation and clean solar power. The host country has to ensure that long term arrangements for power purchase and fuel supply are reliable and predictable. At a later stage further economic instruments should be established to recognize reduction in emissions, for example, the taxation of CO_2 emissions and the international trade of pollution rights. Industrial commitment to solar thermal project development can only materialize with the pull of business opportunity, i.e., a pipeline of projects large enough to justify industrial investments in production facilities and advanced development.

9.3 A Close Look at Solar Thermal Project Developments in 1995

Since 1991, when the construction of the tenth SEGS plant was stopped with the demise of LUZ, no new solar thermal power plants have been constructed. The energy economic environment in the United States has discouraged new solar thermal developments as available revenues - tied to actual gas prices - have not been sufficient for commercial financing. Several companies, however, have been actively engaged in market development to lead solar thermal technology into the next phase of installations. The lead companies - FLAGSOL (Germany), SOLEL(Israel) and Spencer Management (USA) - are exploring new solar thermal parabolic trough projects in the Mediterranean area, Iran, India, and Mexico. Although potential revenues for solar thermal plants in these locales are no more encouraging than in the US, the likelihood

A snapshot of current solar thermal project evaluations can be found in Annex A

of new projects is growing in view of increasing global concerns on CO_2 emissions and the greenhouse effect. In contrast to the decline of incentives in the US and California, it is expected that additional attractive financing mechanisms will be offered to value the environmental benefits of these projects. Because the energy-economic frameworks vary in this group of countries, feasibility studies are conducted to identify sites, determine plant concepts and operational modes and estimate electricity costs.

Annex A contains brief of several of the ongoing major project developments. Although these summaries are but a mid-1995 snapshot of current status, they characterize the activities in planning, and point to the possibilities for a sustainable solar thermal market in the world's sun belt. These projects include:

Location	Type	Net Capacity (net MW_e)
Crete (Greece)	SEGS	52
India	SEGS	35
Iran	SEGS	100
Israel	ISCCS	85
Mexico	ISCCS	312
Morocco	SEGS	80
Nevada	ISCCS	135

The Euro-Maghreb Gas and Electricity Interconnection - A Strategic Option for ISCCS plants in the Mediterranean

In the Mediterranean area 386 million people inhabit an area of approximately 9 million km², with 65% in the north where the economic strength and energy consumption are concentrated. The northern and southern sectors are defined here to be the north-south regions divided by the Mediterranean Sea. The installed power plant capacity was 266 GW in 1992 and is expected to increase to approximately 410 GW in 2005. An additional 190 GW are projected up to 2025, not considering new hydro power and nuclear projects. Over 90% of the imported energy goes to the southern sector.

Over this time horizon it is expected that two-thirds of the future power plants will be installed in the north, where 80% will replace retired capacity. In the south, on the other hand, new construction will dominate. This growth will take place in an environment where permitting of new power stations is an increasingly critical issue, especially in the northern region. As elaborated in the main text, solar thermal electric plants are poised for wider implementation. Ongoing large infrastructure projects can significantly ease the introduction of cost effective solar thermal power plants. In particular, ISCCS plants can supply mid- to base-load power to the rapidly growing countries in the Southern Mediterranean and contribute to the export of electricity to the Northern Mediterranean.

The Spanish National Grid Company, Red Electrica de España (REE), and the Moroccan National Utility Company ONE are carrying out the engineering and construction of the electric submarine cable interconnection between both countries through the Strait of Gibraltar. The first phase, an interconnection capacity of 600 MW, is underway and is expected to be finished in 1998. Provisions are included to allow future conversion of the initial, high voltage alternate current (HVAC) interconnection from alternating to direct current transmission, thereby increasing the capacity of the interconnection to well above 2000 MW after the year 2003.

The second major infrastructure investment is the erection of a gas-pipeline coming from the gas fields in Central Algeria, passing by the Northern part of Morocco, crossing the Strait of Gibraltar and linking the new gas pipeline to the existing one in Seville. From there expansions are planned to go to Lisbon, Portugal. A related protocol was signed in early 1991 and the construction of the pipeline inaugurated in May 1993 by the Energy Ministers of Spain, Morocco and Algeria. The pipeline is designed to transport 4,000 million cubic meters of natural gas per year, equivalent to an electric power capacity of about 1 GW. The investment cost of approximately 3 billion USD are financed by the European Investment Bank. Construction is expected to be completed in 1998. The gas and electric power interconnection between Spain and Morocco is depicted in Figure 9-3.

With the completion of the new gas-pipeline and electricity interconnection, investments in new power generation capacity will focus on gas-fired combined-cycle plants to profit from better economics and, at the same time, minimizing emissions of fossil power generation. The integration of parabolic trough fields into combined-cycle stations will give Morocco and Algeria the opportunity to implement large-scale gas-fired ISCCS thus offering the export of clean electricity to Southern Europe. In summer the solar field production profile will not only coincide with the growing electricity demand from the tourism sector, but will also complement the degradation in performance of gas-fired combined cycles when high ambient temperatures induce capacity and efficiency losses. Furthermore, summer water use in hydro plants can be minimized, freeing scarce water resources for agricultural use.

Figure 9-3 Planned Gas Pipeline and Power Grid Interconnection between Spain and North Africa

In summary the benefits of the new gas and electric link between North Africa and Spain can be ideally complemented with solar thermal technology. Such a strategy would constitute the most straightforward, economic and effective introduction of solar electricity generation into the European electricity market. At the same time a significant amount of jobs will be created, mainly in the emerging Maghreb countries but also in Europe. Solar energy related investments and economic development will be channeled to these emerging regions, where it is of utmost importance to enhance economic stabilization and political support. It is, in fact, for these reasons that the European Union is supporting the infrastructural planning and solar strategy which can lead to a more rapid implementation of ISCCS projects in the region.

Figures

Tables

10. Overcoming the Financing Barriers

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10. Overcoming the Financial Barriers

Successful financing of environmentally benign energy technologies is and will continue to be a major challenge. The key issue is the disparity in present costs between solar thermal power plants (and renewable energy technologies in general) and fossil-fired bulk base-load power generation.

Successful financing of environmentally benign energy technologies is and will continue to be a major challenge

Financing of power plants, specifically in the developing world, has been a continuing problem during the last decade. As discussed in section 2, the financial weakness of the power sector in several countries has limited the construction of urgently needed capacity, and recent entries into privatization have only begun to fill the need. Even then, only the most economical base-load projects have received the necessary financial support, e.g., large scale coal-fired stations or combined cycle units with inexpensive fuel available.

The power generation cost margin for base-load power plants is on the order of 4-6 US cents/kWh. Fossil-fired power plants designed to satisfy mid-load or peak-load demands have somewhat higher LECs due to lower utilization factors. Large wind energy parks are now achieving LECs on the order of about 5-6 US cents/kWh for non-dispatchable electricity when the sites have excellent wind resources. In the future wind projects may encounter limitations in sites with a high wind resource as well as reduced compensation due to the lack of dispatchability. Solar thermal electricity can achieve LECs of about 6-8 cents/kWh for ISCCS plants in mid- to base-load operation, and 9-10 cents/kWh for SEGS plants in mid-load operation. It appears clear that as long as the environmental factors and employment benefits of renewable power production are not valued in the power market, financial and political institutions must implement measures to levelize the competitive playing field.

10.1 Multiple Paths to Financing

The world's energy sector has historically received about 15% of total global investments and comprised about 5% of the world GDP. Future needs are likely to increase both of these figures. The World Energy Council and World Bank anticipate an overall investment of about USD 30 trillion (in 1992 prices) between 1990 and 2020, which is 50% more than the world's entire GDP in 1989. The competition for international funds will intensify and the "conventional" funding available from the World Bank and other multi- and bilateral donors may cover only 20% of the financing needs, with the remainder required from domestic funds and/or private capital.

Developing countries and renewable energy projects will be put in a difficult position under these conditions. Given that priorities will normally be assigned to the most attractive base-load projects representing only the initial needs for economic growth, it will be particularly hard to finance the cost-intensive investments for "clean" technologies.

However, the environmental attractiveness of SEGS projects has created an increasing interest of governments and institutions in Europe, the United States and developing countries to support the implementation of future solar thermal projects. Because this new but proven technology has higher specific investment costs than conventional fossil-fired alternatives, it is widely accepted that innovative financial tools are necessary to attract major investments for a rapid market introduction.

Requirements to meet energy growth demands in developing countries strains even the financing needs for conventional energy plants, much less renewable technologies

Bilateral and multilateral financial institutions are evaluating to what extent such higher initial investment costs - which will result in fuel savings and emission reductions - are cost-effective and the degree to which compensation by attractive financing tools is appropriate. It is acknowledged that this additional investment burden cannot be put on the shoulders of an individual country which needs its financial resources for enhancing its infrastructure and thus creating the basis for economic development. Thus joint support from the European Union, the World Bank and others is required.

10.2 GEF and the World Bank's Solar Initiative

A positive step for renewable energy emerging from the United Nations Conference on Energy and Development (UNCED) at Rio de Janeiro in 1992 was the creation of the *Global Environment Facility (*GEF*)*, an entity providing grants and concession funds to developing countries for projects which protect the global environment. The World Bank is a GEF implementing agency along with the United Nations Development Program (UNDP) and the United Nations Environment Program (UNEP). In its pilot phase, a variety of promising renewable power projects and measures for energy efficiencies have been studied and some solar projects, mainly for small-scale application, have already been financed in developing countries with the support of bilateral and multilateral development agencies and the GEF. The GEF, established on a permanent basis in March 1994, has now moved from a pilot phase into an operational phase. GEF has important activities in the preservation of ecologically sensitive habitats, ozone layer protection, and the introduction of more efficient energy use in the Third World. With respect to renewables, GEF's goal is to support near-commercial applications of proven renewable technologies which can also attract significant co-financing from public and private resources.

A positive step for renewable energy emerging from the 1992 Rio conference was the Global Environment Facility, providing funds to developing countries for projects which protect the global environment

The role of GEF funding is intended to be mainly catalytic, that is, to absorb transactional costs and reduce the risk of investments in "pioneering technologies" by providing grant financing for the uneconomic portion of a project proposal. The grants will typically have a leverage with a proportion of about 3:1, i.e., one USD of grant financing can usually attract three USD of commercial financing.

In the case of solar thermal power plants, the uneconomic portion likely to be eligible for GEF grant financing is the solar field. Although the solar field represents 45 to 55% of the total investment, fuel savings reduce the currently required buy-down to about 20-30% of the total investment.

- ❑ GEF for programs such as PV for rural electrification and solar thermal, wind and biomass-fueled power plants using proven but non-commercial technologies
- ❑ Conventional development financing from the Multilateral Development Banks (MDBs) for projects which have demonstrated their economic competitiveness
- ❑ Equity and loan finance from the International Finance Corporation (IFC), in conjunction with the GEF
- ❑ Direct investments by utility companies
- ❑ Commercial finance, local as well as foreign
- ❑ Private direct investment, local and foreign

Table 10-1 Usual Sources of Financing for Electric Generation

If one examines normal financing sources for power projects (see side box) it is apparent that the only <u>additional</u> fund available beyond normal instruments to balance insufficient economics of renewable technologies is the GEF. Neither the absolute amount of the GEF budget earmarked for solar thermal electricity nor the potential number and size of potential projects is presently clear. In the interim, bilateral protocols could be applied to help to bridge the economic gap of renewables with limited soft loan financing, though their use is unlikely. Although available in principle, there is heavy competition for use of these funds for other urgent infrastructure investments and it is risky to assume that they will be used by the applying host country for investments in renewables. This potential problem has not surfaced yet since none of the pending solar thermal project developments have reached this phase.

The World Bank has initiated a *Solar Initiative* to encourage and facilitate renewable energy projects throughout the world. A tentative list of potential activities is detailed in the accompanying box and is intended to accelerate projects in various technologies and applications in order to demonstrate commercial readiness and thus ease the financing of future projects.

- ❑ 3 x 100 MW of solar thermal plants with a focus on parabolic trough technology
- ❑ 20 - 50 MW of PV for small scale uses, rural electrification, water pumping, electricity supply for health clinics, street lighting, and schools
- ❑ Several 100 MW of wind power projects
- ❑ 1 or 2 biomass power plants on the order of 50 MW each
- ❑ Several programs of village powering, probably using a blend of different renewable power technologies
- ❑ Programs to apply solar thermal low to medium temperature heat for agriculture and industry

Table 10-2 List of Potential Activities of the World Bank Solar Initiative

10.3 Financing Opportunities from the European Union

Since the mid 70's, the Commission of the European Community, now the European Union, has supported research and development on renewable energy technologies and funded a series of pilot and demonstration solar facilities. The flow of these funds to the member countries has been quite often higher than the national R&D and demonstration budgets. In 1994, the European Union released a major research and development demonstration program, the so-called “Fourth Framework” program for clean and efficient energy technologies comprised of the JOULE and THERMIE elements. The program lasts until 1998 and has earmarked 450 million ECU (570 million USD) for renewable programs over its time horizon. Solar thermal power, specifically parabolic trough technology, is considered to be the only solar power technology which has reached commercial, large scale. It is expected that this technology has important export potential, specifically for the Mediterranean area.

The European Union has been a strong and consistent supporter of projects to develop and implement renewable energy systems

Therefore, the European Union welcomes and supports R&D proposals such as direct steam generation for parabolic troughs and is anticipating major demonstration proposals in a southern European member state. Financial support for large scale solar thermal demonstration plants is expected to be 40% of the “non-conventional” portion of the plant in the form of grant financing, e.g., for the solar field investment . This translates to about 20% of the total solar plant investment cost. The joint JOULE-THERMIE program is administered by the Directorate General for Energy (DG XVII) and the Directorate General for Science, Research and Development (DG XII).

Also apparent is an increasing interest in solar thermal power by the Directorate General for Regional Cooperation (DG XVI), which administers the flow of funds to less developed regions in the European Union. They have established a specific action program on energy and the environment to tackle the increasing concerns about the environmental impacts of large infrastructure programs. If the project host country applies for financing to the European Union, grant elements up to 50% of the total investment are made available for specific emerging regions.

The European member states which can benefit from solar power projects are limited by the availability of a good solar resource to southern Spain, the Greek islands and, to a lesser extent, southern Italy. However, large attractive potential markets for solar thermal power generation exist in the adjacent southern Mediterranean countries, and initiatives of the European Union’s Directorate General for External Relations (DG I) are important to note. This is underlined by the conclusions of the November, 1995 Barcelona Conference in which an intensified cooperation with the southern Mediterranean countries was agreed upon and the Med-Energy program was launched, aiming at environmentally responsible energy cooperation. Because energy and environment are a key focus for the cooperation with the southern Mediterranean neighbors, DG I early recognized the benefits of solar thermal power generation - large investments in an environmentally responsible infrastructure create jobs in export industries in Europe as well as in manufacturing facilities in the countries of concern. These benefits would improve the economic perspective for these countries and help stabilize the political environment. As a consequence, DG I took the lead in supporting a technology assessment and pre-feasibility study for a solar thermal project development in Morocco. The Directorate General also welcomes similar proposals from other southern neighboring countries in the Mediterranean.

10.4 Joint Implementation - a Possible Financing Tool

During the Rio follow-up conference in April 1995 (United Nations' Contracting Parties Conference on Climate Change in Berlin), a new concept of cooperation between the industrialized countries and the developing world, termed *joint implementation,* was introduced. Utility companies in OECD countries have recognized that investments in further reducing the emissions in their own efficient facilities are less effective than the same investment for the rehabilitation or new construction of a state-of-the-art fossil power plant in the developing world. While average thermal power plant efficiencies are on the order of 35 - 40% for steam plants and 50% and more for combined cycles in industrialized countries, average efficiencies of 25 to 35% for steam cycle units can be encountered in the developing world. If utility companies in industrialized countries are obliged to reduce the emissions of their power plants to a certain level, it can be more cost effective to invest this money in the Third World. The incentive to invest this money, however, only exists if certain emission levels are binding for the utility companies through instruments like the taxation of emissions, resulting in an expense which can be written-off if emission levels are reduced elsewhere in the world by the utility company.

The implementation of schemes to introduce a carbon dioxide or energy tax or trade of emission rights is under controversial discussion in the industrialized countries. In order to avoid such additional cost burdens, some utility companies have already offered to their respective governments that they will organize actions with the same emission reduction effect on a private basis without governmental regulation. It is in question whether these actions will be taken without a regulatory background and the resulting incentive in pollution reduction. However, the Berlin conference agreed upon a pilot phase of joint implementation actions, and some OECD governments have already started a national joint implementation phase, reviewing project proposals from companies in the energy sector aimed at investments in emission reductions in countries abroad, mainly central and eastern European countries, states of the former Soviet Union and some developing countries.

Shouldsuch a joint implementation program materialize on a large scale, considerable additional funds will be made available through the investments of utility companies from the OECD. These programs will not necessarily benefit renewable technologies. On the contrary, utilities may only seek projects which are cost competitive today and will have sufficient returns on invested capital. The logic of the utility companies is that there are certain risks involved in financing energy projects outside their influence zone, such as exchange rate and policy risks, and additional economic burdens will not be accepted. On the other hand, renewable power projects are opening new markets for utility companies from industrialized countries and offer more efficient utilization of renewable technologies in the sun belt of the world.

10.5 Financing Solar Power - Summary Recommendations on the Need for Concerted Action

It is obvoius that an economic gap exists between solar power plants and conventional base-load fossil-fired thermal power plants. This gap is on the order of 1 cent/kWh for base-load operating ISCCS plants and 2 to 3 cents/kWh for mid-load operating SEGS plants, which translates to an initial need for compensation such as tax credits on the order of 18 to 33% of the total solar plant investment cost. If clean power is acknowledged to be a key to a sustainable economic and energy growth, implementation measures have to be taken to build up the necessary network and manufacturing infrastructure to respond to the future challenges. This implies that additional funds have to be made available on a large scale in order to promote the market introduction of environmentally responsible renewable power production.

- ***Levelizing the playing field helps reduce otherwise needed subsidies***

Higher electricity compensation from the host country of a solar power plant will reduce or even avoid the need for subsidies. Rates based on the **real** power generation cost of new fossil-fueled thermal power plants are required, with a margin reflecting the additional risk associated with operating a plant abroad. Tax incentives should also be considered by the host country. Since solar thermal trough power plants have a high local scope of supply, resulting in new jobs, in-country tax support appears warranted.

- ***Additional financing beyond conventional instruments is required***

GEF funds are the only *additional* financing provided which do not compete with other investment priorities of the host country. These funds, therefore, should be offered to carry the main portion of the “uneconomic” part of the solar plant at the current stage of the technology. This does not imply that support is required for projects which are economically unsound. Rather it is a recognition that promising low- or non-polluting technologies may have higher power generation costs than conventional technologies because they partially balance the environmental impacts of those technologies. Support is justifiable only for power systems that are environmentally benign, close to economic competitiveness and promise significant emissions reductions.

Existing financial protocols from multilateral or bilateral institutions should also be reviewed to give increased incentive and to focus on renewable energy investments. These soft loans will further help to bridge the economic gap, and such priorities will place solar proposals in a more advantageous position in relation to other urgently needed infrastructure investments.

- ***The IFC and others should provide special considerations for IPP projects***

With the increasing importance of independent power projects, the International Finance Corporation (IFC) should consider larger equity funds and extended help in syndicating the remaining loan financing in order to reduce transaction and administrative costs for these pioneering projects. The same approach should be followed by the various national investment banks for private investment in developing countries. These measures are warranted because even when the economic gap is bridged, independent power projects represent higher risks than similar power projects financed via direct utility purchase.

- ***The R&D infrastructure and utilities have special roles in developing renewable energy projects***

A major task for institutions supporting R&D as well as industry engaged in technology export, is to organize effective R&D programs oriented to the needs of the project developers plus efficient supply and operating consortia to build up expertise and manufacturing capabilities. Then, when a stream of projects justifies mass production, these mechanisms can act to drastically reduce the initial cost investment in manufacturing facilities. The role of utility companies from the industrialized world will become increasingly more important in both financial participation and training for efficient operation of power plant parks.

- ***Appropriate signals from the political arena are necessary and effective***

Last, but not least, politicians in industrialized countries need to provide stronger support of financing protocols for renewable energy projects in the sun belt. This support should be evident in addresses on policy and on budget decisions affecting renewables, even under conditions of tight budgets. Therefore, rather than a parochial support of “showcase” projects within their own countries, politicians need to take a broader view to support large-scale solar projects in areas where there exists a convergence of superior demand, siting and financing conditions. Politicians from developing countries should recognize that the readiness of the industrialized world to support renewable power in the sun belt can only be expected if the energy economic environment in the Third World is attractive enough for power investments.

Tables

ANNEX A: SEGS and ISCCS Project Development Activities - Status as of December, 1995

Rev. 11-Jul-00

PROJECT LIST

Location	Type	Net Capacity (net MW_e)
Crete (Greece)	SEGS	52
India	SEGS	35
Iran	SEGS	100
Israel	ISCCS	85
Mexico	ISCCS	312
Morocco	SEGS	80
Nevada	ISCCS	135

Crete / Greece		
Site location	**Frangokastello, Sfakia, Southern Crete**	
Net capacity	**52**	**MWe**
Configuration / Type	**SEGS**	(Rankine Cycle)
Solar field size	297,570	m²
Fossil back-up / fuel	Boiler	/ Fuel oil #2
Annual solar radiation (direct normal)	2,293	kWh/m²yr
Net electricity production	202,689	MWh/yr
Solar production	55	%
Annual full-load hours	3,900	h
Investment cost	180.9	million USD
Specific investment cost	3,480	USD/kW
Levelized electricity cost (IEA methodology)	10.7	UScents/kWh
Fuel related LEC of gas turbines in Crete, today	17	UScents/kWh
Project Developer:	OADYK (Chania, Crete), FLAGSOL	
Potential Owner / Operator:	PPC (Public Power Corporation, Athens and Iraklion)	

Project Development Status:

Under contract with the development organization for Western Crete, OADYK and with the financial support of the Greek Ministry of National Economy and the European Union's Directorate XVI (Regional Development), a detailed pre-feasibility study was conducted in 1993/94. Since the beginning of 1995, the governor of the Region of Crete has discussed the recommended 52 MW SEGS project with the Greek national utility company, Public Power Corporation (PPC), which is responsible for the electricity supply on the island grid of Crete. Power demand in Crete is growing strongly at about 8% per year and the electricity system currently suffers periodic black-outs and brown-outs due to delays in expanding capacity. To replace costly gas turbine operation, PPC prefers to erect two 60 MW fuel-oil-fired oil-steam plants with power generation costs on the order of 7 UScents/kWh. The region of Crete, however, is reluctant to approve these projects due to the environmental concerns of the strong local tourism industry and insists on the intensified use of renewable energy technologies. In this situation, PPC is increasingly forced to make use of the old gas turbine units with fuel costs alone contributing about 17 UScents/kWh to total electricity cost. The European Union's DG XVI has indicated its interest in co-financing a solar thermal project to the Greek government, while the EU's Energy Directorate DG XVII is expecting an official proposal of this project under its THERMIE program.

India		
Site location	**Jodhpur / Rajasthan, North-West India**	
Net capacity	**35**	**MWe**
Configuration / Type	**SEGS**	(Rankine Cycle)
Solar field size	209,280	m² (estimated)
Fossil back-up / fuel	Boiler	/ Gas
Annual solar radiation (estimated)	2,200	kWh/m²yr
Net electricity production	70-90,000	MWh/yr
Solar production	70-100	%
Annual full-load hours	2,000-2,600	h
Investment cost (estimated)	110	million USD
Specific investment cost	3,100	USD/kW
Levelized electricity cost (IEA methodology)	to be evaluated	
Average LEC of new, fossil-fueled gas and oil steam plants at 6,000 full-load h/yr	4.5-7.5	UScents/kWh
Project Developer:	SOLEL (Israel), BHEL (India)	
Potential Owner / Operator:	IPP	

Project Development Status:

In 1987/88, the then SEGS developer and operator, LUZ International Ltd., Los Angeles, carried out a pre-feasibility study on the erection of a 30 MW SEGS plant in India on behalf of the Department of Non-conventional Energy Sources (today the Ministry of Non-Conventional Energy Sources, or MNES). In 1989, the German development bank KfW contracted FICHTNER to perform an independent feasibility study which was presented in 1991. Since 1994 the Israeli-Belgian company SOLEL, which took over the production line of LUZ in Israel, has been actively exploring the feasibility of a project in the state of Rajasthan with the Indian engineering firm Balpour Heavy Electric Industries, Ltd. At the end of 1994, MNES officially requested co-financing of a 35 MW SEGS plant from the GEF/World Bank and KfW. At the same time, the Department of Energy of the Federal State of Rajasthan solicited an expression of interest from potentially interested enterprises to offer the project on a Build, Operate, Own and Maintenance (BOOM) scheme. As of mid 1995, it has been proposed to expand the feasibility study to analyze an ISCCS configuration in addition of a SEGS plant.

Iran		
Site location	**Yazd / Central Iran**	
Net capacity	**100**	**MWe**
Configuration / Type	**SEGS**	(Rankine Cycle)
Solar field size	601,680	m² (estimated)
Fossil back-up / fuel	Boiler	/ Gas
Annual solar radiation (direct normal)	2,400	kWh/m²yr
Net electricity production	220,000-315,000	MWh/yr
Solar production	70-100	%
Annual full-load hours	2,200	h
Investment cost (estimated)	240	million USD
Specific investment cost	2,400	USD/kW
Levelized electricity cost (IEA methodology)	to be evaluated	
Average LEC of new, fossil-fueled gas and oil/steam plants at 6,000 full-load h/yr	4 - 5.5	UScents/kWh
Household tariff	1	UScents/kWh
Project Developer:	FLAGSOL, FICHTNER, MATN (Tehran)	
Potential Owner / Operator:	TAVANIR (Tehran)	

Project Development Status:

The government and electricity sector of the Islamic Republic of Iran has shown a significant interest in large scale solar thermal power plants, proposing a collaboration in 1993 to the Federal Republic of Germany with the goal of erecting a 100 MW solar thermal power station. In late 1993 and early 1994 a joint German-Iranian expert group developed a project definition for a 100 MW SEGS-type plant on behalf of the Federal Ministry of the Environment, Bonn, and the Ministry of Power, Tehran. The joint expert group recommended a full feasibility study. After agreeing with this recommendation in March 1994 and approving a 50% cost-share in autumn 1994, the Iranian government officially requested financial support from the GEF. Further steps are expected once financing of the feasibility study is secured.

Israel

Site location	**Israel, Negev Desert**[1]	
Net capacity	**85**	**MWe**
Configuration / Type	**ISCCS**	
Solar field size	196,200	m^2
Fossil back-up / fuel	Gas turbine / Gas	
Annual solar radiation (estimated)	2,200	kWh/m^2yr
Net electricity production	300,000	MWh/yr
Solar production	20-25	%
Annual full-load hours	3,700	h
Investment cost	127	million USD
Specific investment cost	1,588	USD
Levelized electricity cost (IEA methodology)	to be evaluated	
Expected revenue from IEC	7.1	UScents/kWh

Project Developer: SOLEL (Israel)

Potential Owner / Operator: Private Consortium

Project Development Status:

Feasibility studies on this project were begun in 1987 by LUZ Industries, Israel (LII) and continued with the financial support of FLAGSOL until 1990. An 80 MW solar thermal plant has been included in the national electricity expansion planning. After the bankruptcy of LUZ, project development activities were revived by SOLEL, the Israeli-Belgian company which bought the assets of LII. SOLEL performed a pre-feasibility study for an 85 MW ISCCS plant in 1994. The Israeli Electric Company will call for bids during 1996 for a hybrid solar thermal plant with a minimum net capacity of 80-100 MWe. This is part of a sequence of bids where the private sector is invited to undertake up to 10% of the national generating capacity (~ 9 GW by 2000) in different generation technologies. The bid details are yet to be defined, but the allocation and concept was determined based on a plant suggested by SOLEL as summarized above.

[1] Permitting and natural gas availability require consideration of other sites

Mexico		
Site location	**Northern Mexico**	
Net capacity	**312**	**MWe**
Configuration / Type	**ISCCS**	
Solar field size	341,000	m^2 (estimated)
Fossil back-up / fuel	Gas turbine / Gas	
Annual solar radiation (estimated)	2,835	kWh/m^2yr
Net electricity production	2,460,000	MWh/yr
Solar production	8.1	%
Annual full-load hours	7884	h
Investment cost	244	million USD
Specific investment cost	780	USD/kW
Levelized electricity cost (with rapid depreciation and 50 million USD GEF grant)	3.13	UScents/kWh
Target LEC of new, gas-fueled combined cycle plants at 7,000 full-load h/yr	3.25 or less	UScents/kWh
Project Developer:	Spencer Management Associates (California)	
Potential Owner / Operator:	IPP or Commission Federal de Electricidad, CFE (Mexico City)	

Project Development Status:

With financial support of the Rockefeller Foundation, the US Electric Power Research Institute and several member utilities, the national labs Sandia and NREL, and the support and collaboration of BECHTEL Enterprises, Spencer Management, a California-based project developer, performed a pre-feasibility study which examined the conceptual design and performance of a number of ISCCS options located in central to northern Mexico or Baja California. The study focused on a 312 MW integrated solar combined cycle system located in Mexicali operating at base-load (90% capacity factor) with a solar share of approximately 8%. The World Bank/GEF showed its interest and support of the objectives of the Spencer study, which has as its major goal an official request by the Mexican government in early 1996 for co-financing and grant financing through the World Bank, IFC and GEF. The intent of the GEF grant is to buy down the competitive margin between an ISCCS project without grant and a competitive gas-fired combined cycle. The project cost includes the impact of selected procurement within Mexico as well as recent devaluation of the Mexican peso.

Morocco		
Site location	**Ouarzazate / Southern Morocco**	
Net capacity	**80**	**MWe**
Configuration / Type	**SEGS**	(Rankine Cycle)
Solar field size	470,880	m²
Fossil back-up / fuel	Boiler	/ Fuel oil #2
Annual solar radiation (direct normal)	2,364	kWh/m²yr
Net electricity production	337,500	MWh/yr
Solar production	51	%
Annual full-load hours	4,200	h
Investment cost	265	million USD
Specific investment cost	3,300	USD/kW
Levelized electricity cost (IEA methodology)	12.6	UScents/kWh
Average LEC for new fossil power plants at 6,000 h/yr in Morocco	6 - 8	UScents/kWh
Project Developer:	FLAGSOL	
Potential Owner / Operator:	O.N.E. (Casablanca) or IPP	

Project Development Status:

Under contract with the Directorate General I (External Relations) of the European Union, FLAGSOL in cooperation with ENDESA, Spain’s largest utility company, performed a detailed technology assessment and pre-feasibility study in 1993/94 for various site locations in Morocco. In mid 1994, the Moroccan Energy Ministry submitted the final report of the study to the World Bank group and asked for financial support of an oil-fired 80 MW SEGS project in Ouarzazate. In 1995, negotiations between the Moroccan Energy Ministry, Moroccan state electricity organization O.N.E., European Union and World Bank sought to find appropriate financing mechanisms so that the additional cost of the solar thermal plant compared to a conventional fossil-fueled power plant would be carried by these multilateral financing institutions. With this approach, no disadvantage for the Moroccan energy sector ensues with the introduction of an environmentally responsible new power technology. After various discussions, the cooperating organizations agreed in June 1995 that a complementary feasibility study should focus on the implementation of an ISCCS plant in proximity to the Euro-Maghreb gas pipeline which is under construction in northern Morocco. This study will contrast larger capacities and gas firing to the previous findings. Final results are expected to be available by autumn 1996 and will constitute the basis for a GEF and European Union’s financing request.

Nevada	
Site location	**Southern Nevada**
Net capacity	**135 MWe**
Configuration / Type	**ISCCS**
Solar field size	125,000 m² (estimated)
Fossil back-up / fuel	Gas turbine / Gas
Annual solar radiation (estimated)	2,700 kWh/m²yr
Net electricity production	806,000 MWh/yr
Solar production	8 %
Annual full-load hours	6,000 h
Investment cost	135 million USD
Specific investment cost	1000 USD/kW
Levelized electricity cost (IEA methodology)	not available at this time
Average LEC of new, fossil-fueled gas and oil steam plants at 6,000 full-load h/yr	not available at this time
Project Developer:	Spencer Management Associates (California)
Potential Owner / Operator:	IPP

Project Development Status:

With the projected closure of the federal nuclear test site in southern Nevada, USA, a consortium of federal, state and local government agencies in 1994 conceived a plan for solar power development in the area, which is characterized by excellent solar resources and a high electricity demand growth. In particular, the solar resource peaks coincident with a very high regional demand for air conditioning. The Corporation for Solar Technology and Renewable Resources, CSTRR, was established in 1995 to facilitate the solar development process. In mid-1995, CSTRR issued a request-for-proposals for proposed solar installations. A prime objective of the solar development was to take advantage of the industrial infrastructure at the Nevada Test Site and to otherwise promote Nevada industry through local production or construction employment. Spencer Management, a California-based project developer, responded with a proposed ISCCS plant of 135 MWe net capacity with the characteristics shown above. This project was one of five projects selected for further review by CSTRR in early 1996. Electricity would be purchased by WAPA, the Western Area Power Administration, or another highly integrated participant who can offer premium electricity rates for green power generated in peak demand periods. The project proposed by Spencer Management has a strong technical and economic basis in the extensive pre-feasibility study carried out by the firm to examine the conceptual design and performance of a number of ISCCS options located in central to northern Mexico. Financial support for that work came from the Rockefeller Foundation, the US Electric Power Research Institute and several member utilities, the national labs Sandia and NREL, along with the support and collaboration of BECHTEL Enterprises, All six notable project developments presented above are based on parabolic trough technology. But, to complete the snapshot on actual ongoing solar thermal activities, we include a summary of a central receiver concept, the PHOEBUS Solar Power Tower, developed by a German industrial consortium and intended to be the next step in power tower technology on a commercial basis. Because this section is focused on the presentation of commercial solar thermal projects, information is not included on pilot and demonstration plans for solar tower systems like the Spanish SOLGAS 7 MW central receiver plant integration into an existing 65 MW steam turbine or the US Solar Two 10 MW test facility, the recent demonstration successes of parabolic dish systems or the 5 MW pilot solar chimney concept.

PHOEBUS		
Site location	**Wadi Rum, Jordan or Brazil or Iran**	
Net capacity	**30**	**MWe**
Configuration / Type	**Solar Tower**	
Solar field size	163,500	m^2
Fossil back-up / fuel	Boiler / Gas or Fuel oil #2	
Annual solar radiation (direct normal) in Jordan	2,500	kWh/m^2yr
Net electricity production	112,800	MWh/yr
Solar production	50,2	%
Annual full-load hours	3,760	h
Investment cost (estimated)	122.4	million USD
Specific investment cost	4,080	USD/kW
Levelized electricity cost (IEA methodology)	18.0	UScents/kWh
Project Developer:	STEINMÜLLER and FICHTNER, Germany	

Project Development Status:

During the 1986-1993 time frame an international industry consortium, mainly German-based but with support of Swiss and US companies, developed a commercial demonstration solar tower power plant of 30 MW capacity. After intensive discussions, the German party favors a volumetric air receiver concept while the American companies are furthering the molten salt concept. As a result, recent development activities have split: the US companies are rehabilitating the existing 10 MW Solar One test facility in Barstow, California, as Solar Two, while the German consortium has run successful tests of the volumetric air receiver on a 3 MW_{th} scale at the Plataforma Solar de Almeria. Further project development activities are concentrated on an appropriate host country and site location. Jordan has been chosen to be the prime project host country with significant interest from the Jordanian Government and its electricity company JEA. However, other countries like Brazil and Iran are also under consideration and a final host country has not yet been chosen.

ANNEX B: BIBLIOGRAPHY

1. T. B. Johansson, et. al, Editors, Renewable Energy - Sources for Fuels and Electricity, Island Press, Washington, D.C., 1993:
   Ch. 1. T. B. Johansson, et.al, “Renewable Fuels and Electricity for a Growing World Economy: Defining and Achieving the Potential”
   Ch. 3: P. De Laquil, et. al, “Solar Thermal Electric Technology”.
2. Assessment of Solar Thermal Trough Power Plant Technology and its Transferability to the Mediterranean Region, FLAGSOL-Grupo ENDESA-CDER for European Commission Directorate General I, Final Report, June 1994.
3. Pre-Feasibility Study on Solar Thermal Trough Power Plants for Spain, FLAGSOL for Grupo ENDESA, Final Report, May 1994.
4. IEA/OECD, World Energy Outlook, Paris, 1994.
5. World Energy Council, Energy for Tomorrow’s World, London, 1994.
6. D. Anderson and K. Ahmed, “Renewable Energy Technologies: A Review of the Status and Costs of Selected Technologies”, World Bank Technical Paper No. 240, Energy Series, 1994
7. Deutscher Bundestag (Enquete-Commission: Protection of the Earth’s Atmosphere), Editor, More Future for Our World - A Sustainable Energy Policy for Climate Protection, Bonn, 1995 (in German).
8. A. Voβ, et. al, “Technological, Economic and Ecological Aspects of a *Global Link*”, VDI Symposium on Global Link-Intercontinental Energy Interconnection, Essen, 1994 (in German).
9. R. Aringhoff, “Energy Policy and CO_2 Reduction Potentials: Are Solar Thermal Power Plants Capable to Contribute?”, Forum Clausthal, Clausthal-Zellerfeld, 1995 (in German).
10. M. Geyer, et. al, “Parabolic Troughs for Commercial Markets”, 7th International Symposium on Solar Thermal Concentrating Technologies, Moscow, September 1994.
11. H. Klaiβ, F. Trieb, “Cost Comparison of PV and Solar Thermal Trough Power Plants”, DLR internal working reports 94-112, Stuttgart, 1994 (in German).